Study Tip

Problems often will refer to conditions of temperature and pressure simply as SATP. Keep in mind that conditions of standard ambient temperature and pressure are defined as a temperature of 25°C and a pressure of 100 kPa.

Sample Problem: Calculating the Release of Heat

Problem

When a 2.1 kg sample of hot water in a kettle was cooled, its temperature decreased from 96.2°C to 18.5°C. How much heat did the water release?

What Is Required?

You need to calculate the quantity of heat released by the water.

What is Given?

You know the mass of water: $m = 2.10$ kg
You know the initial temperature: $T_{initial} = 96.2°C$
You know the final temperature: $T_{final} = 18.5°C$
You have the specific heat capacity of liquid water from Table 5.1 on page 280 of your textbook: $c = 4.19$ J/g·°C

Plan Your Strategy	Act on Your Strategy
Determine the change in temperature of the water.	$\Delta T = T_{final} - T_{initial}$ $=$ _____ °C − _____ °C $=$ _____ °C
Determine the amount of heat released by the water. Use the formula $Q = mc\Delta T$. Remember to convert mass to grams if necessary. A negative sign in the answer means that heat was released; a positive sign means it was absorbed.	$Q = mc\Delta T$ $= (\_\_\_\_\_\ \cancel{kg})\left(\frac{1000\ \cancel{g}}{\cancel{kg}}\right)\left(\_\_\_\_\_\ \frac{J}{\cancel{g}\cdot\cancel{°C}}\right)(\_\_\_\_\_\ \cancel{°C})$ $=$ _____ J $=$ _____ kJ The water released _____ kJ of heat.

Check Your Solution

Check that the solution has the correct number of significant digits. Check that the units are correct. Check that the sign is negative, meaning heat was released, as expected.

Learning Check

1. K/U Identify each of the following systems as open, closed, or isolated.

   a. The universe _____

   b. A ceramic mug of hot chocolate _____

   c. A sealed metal canister _____

   d. An automobile with all doors, windows, and vents closed _____

   e. A sealed, insulated container _____

   f. A stoppered Erlenmeyer flask _____

2. C State the first law of thermodynamics and explain how it relates to the relative enthalpy changes of a system and its surroundings.

   _____

   _____

   _____

   _____

3. A How much heat has a 2.56 kg slab of concrete released on a cool evening if its temperature decreases from 22.32°C to 13.21°C? The specific heat capacity of concrete is 0.88 J/g·°C.

   _____

4. T/I A 25.00 g sample of water is heated to a temperature of 38.0°C, absorbing 2.96 kJ of heat. What was the initial temperature of the water? The specific heat capacity of liquid water is 4.19 J/g·°C.

   _____

Study Tip

Because the unit for specific heat capacity includes grams, be sure to express mass in those units when using the formula to calculate absorption or release of heat.

Enthalpy and the Second Law of Thermodynamics (5.1)

To express thermochemical changes in a process, chemists use **enthalpy, H**, a variable that is not affected by the conditions under which the process occurs. Enthalpy, also called the heat constant of the system, is the total energy of the system plus the pressure times the volume. The enthalpy change of a system depends only on the system's initial and final states.

A positive enthalpy change means that heat has entered the system. This type of process is referred to as **endothermic**. A negative enthalpy change means that heat has left the system. Such a process is referred to as **exothermic**. If two systems or objects are in thermal contact, the **second law of thermodynamics** applies. This law states that heat will be transferred from the object at the higher temperature to the object at a lower temperature until the temperatures of the two objects reach thermal equilibrium.

> **The Second Law of Thermodynamics**
> When two objects are in thermal contact, heat is always transferred from the object at a higher temperature to the object at a lower temperature until the two objects are at the same temperature.

Thermal contact means that the systems are able to transfer thermal energy via collisions. When separated by an insulating material such as foam, systems are considered not to be in thermal contact.

Categories of Enthalpy Changes (5.1)

Two physical changes in systems that are associated with easily studied changes in enthalpy are 1) the dissolving of one substance into another, and 2) phase changes. Larger enthalpy changes occur when chemical reactions take place. Nuclear changes involve the greatest enthalpy changes.

A Summary of Enthalpy Changes

Category of Change	Details	Range of ΔH values (kJ/mol)
Physical change	**Enthalpy of Solution** Bonds between solute and solvent molecules or ions break; bonds between solute and solvent molecules or ions form. The resulting overall enthalpy change is the **enthalpy of solution, $\Delta H_{solution}$.**	±0.44 to ±40.7
	Enthalpy of Phase Changes All phase changes are accompanied by characteristic enthalpy changes. The changes associated with melting, freezing, vaporization, and condensation are related as follows: $\Delta H^{\circ}_{melt} = -\Delta H^{\circ}_{fre}$ $\Delta H^{\circ}_{vap} = -\Delta H^{\circ}_{cond}$ Note that the symbol nought, °, represents standard conditions.	
Chemical change	Energy changes result from the breaking and formation of bonds.	±196.4 to ±890
Nuclear change	Energy changes result from changes in the nuclei of elements, called nuclear changes. Unlike with chemical or physical changes, mass changes are involved. The resulting energy change when mass is converted to energy is calculated by Einstein's $E = mc^2$, where m is the mass converted into energy and c is the speed of light.	-1.13×10^8 to -2×10^{10}

Learning Check

1. A Your friend Juno says that if you close all windows, doors, and vents in a parked car on a hot day, the inside of the car will stay cool because no hot air can get in. Using the second law of thermodynamics, explain why Juno's reasoning is faulty.

2. C A sample of water freezes, releasing 23.5 kJ of heat to the surroundings. If the same sample of water were to melt, how much heat would be absorbed by the system? Explain your answer.

3. A One type of cold pack is made up of two pouches. One contains water and the other contains ammonium nitrate. To activate the cold pack, you squeeze the outer package, breaking the inner pouches and allowing the water and ammonium nitrate to mix. The pack becomes very cold as the ammonium nitrate dissolves.

   a. What type of enthalpy change is involved here? _____

   b. Is this an endothermic or exothermic process? _____

   c. Which has a greater total enthalpy: the original bonds existing in the ammonium nitrate salt and the water, or the bonds that form between the solute and solvent as the ammonium nitrate dissolves?

Study Tip

Use this mnemonic to help you remember the difference between exothermic and endothermic processes: In an **ex**othermic process, heat **ex**its the system. In an **en**dothermic process, heat **en**ters the system.

Enthalpy Changes and Chemical Reactions (5.2)

The enthalpy changes in chemical reactions are due to the changes in energy that result when chemical bonds are broken and formed.

- Breaking bonds requires energy and is therefore an endothermic process.
- Forming bonds releases energy and is therefore an exothermic process.

The difference between the energy required to break the bonds in the reactants and the energy released when the bonds in the products form is equal to the overall energy change for a given reaction.

Thermochemical Equations and Enthalpy Diagrams (5.2)

When a process takes place under conditions of constant pressure, the enthalpy change of a system is equal to the amount of heat that the system gains or loses. A thermochemical equation that describes a chemical reaction includes the value for the enthalpy change of the reaction. There are two commonly used ways to write thermochemical equations, as shown in the table on the next page.